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(54) **A metal composite drive shaft and method of fabrication thereof**

(57) A high specific modulus shaft 1 for a gas turbine engine has a metal outer tube 2 to transmit the torque and a metal and high modulus filament composite sleeve 3 bonded to the tube's inner surface. The composite sleeve 3 is fabricated and bonded to the inner diameter of the tube 2 by winding a composite composition tape on a mandrel with the filaments axially aligned. The mandrel is then inserted into the metal outer tube 2. The assembly is encapsulated, evacuated and sealed and the mandrel pressurized at a sufficient temperature to achieve consolidation and diffusion bonding of the wound composite to itself and to the shaft inner surface.

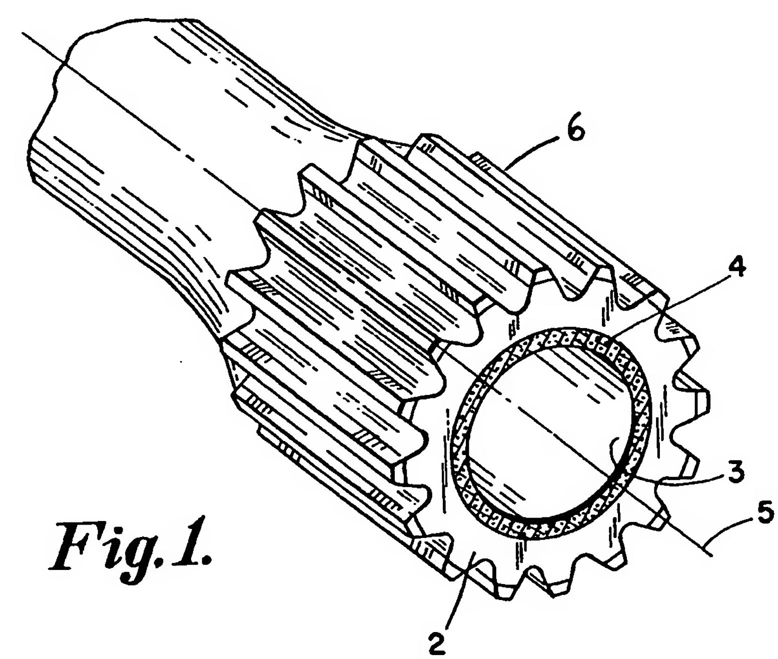

Fig. 1.

The drawings originally filed were informal and the print here reproduced is taken from a later filed formal copy.

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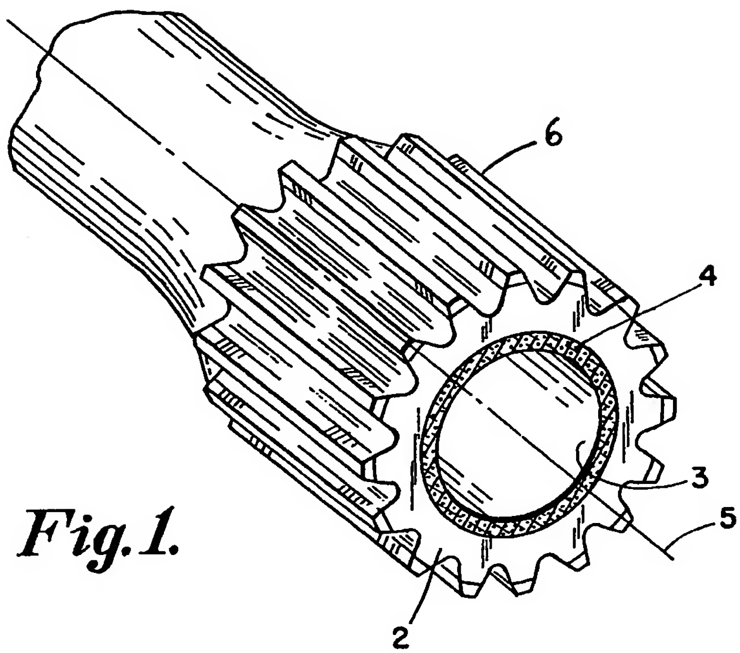

Fig.1.

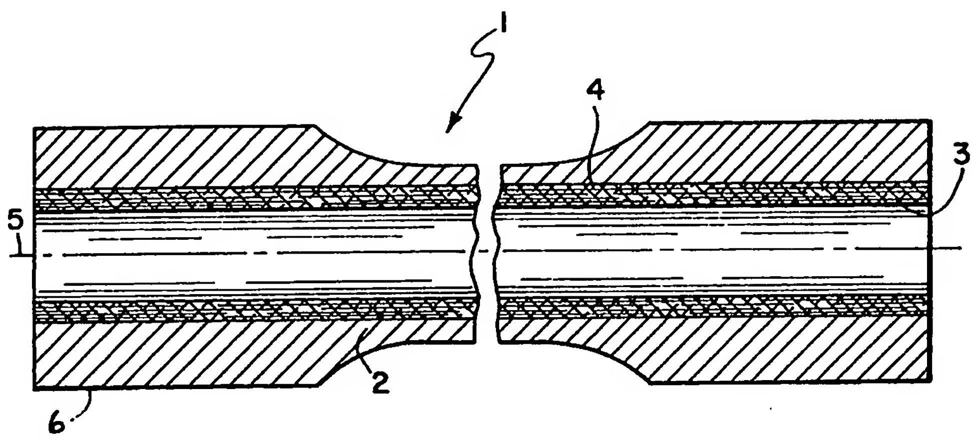

Fig.2.

SPECIFICATION

A metal composite drive shaft and method of fabrication thereof

The present invention relates to a metal composite drive shaft and method of fabrication thereof.

One persistent trend in the gas turbine industry is the development of a smaller, more efficient engine with increased specific power. These changes invariably result in correspondingly higher speed and stress levels on the principal engine components. An engine drive or power shaft is a prime example of this condition since the combination of increased rotor speed and smaller shaft diameter create critical speed problems. One solution is to decrease the effective shaft length by adding additional bearing supports. This creates added mechanical complexities to achieving and assembling a smaller engine. A simpler and more practical solution to the problem is to construct shafts with higher modulus to density ratio which will result in an increased specific stiffness and critical speed.

A first aspect of the invention provides a composite shaft having a high specific modulus comprising:

an outer tubular sheath constructed of machinable high torsion resistant material and having an interior axially extending passage; and

an interior shell constructed of a metal matrix containing axially aligned filaments of a high modulus material, said shell being completely consolidated and bonded on the inner surface of the tubular sheath.

A second aspect of the invention provides a method of fabricating a composite shaft having a high specific modulus comprising the steps of:

constructing an outer tubular sheath of machineable high torsion resistant material and having an interior axially extending passage;

constructing a metal matrix tape having longitudinally extending high modulus material filaments imbedded therein;

rolling the matrix tape on a mandrel with the high modulus filaments orientated in an axial direction;

inserting the tape and mandrel into the axially extending passage to be in close contact with the inner surface of the tubular sheath; and

subjecting the said assembly to sufficient temperature and pressure to achieve consolidation and diffusion bonding of the filament reinforced metal tape into the outer tubular sheath.

The combined metal and composite shaft of the invention is constructed to withstand the torsional and bending stresses placed on a small diameter drive shaft for a gas turbine engine. In one preferred method, an outer tubular steel shaft is constructed; the boron filaments are carefully positioned and spaced between two thin film layers of aluminium to form an aluminium sheet having interior longitudinally oriented boron filaments; the boron/aluminium sheet is rolled onto a mild steel mandrel and inserted into the tubular steel shaft with the filaments aligned axially; the assembly is placed in an autoclave which is first pressurized to 4 to 5 ksi (kilopounds per square inch) ($2.8 - 3.5.10^7$ N m^{-2}), heated to 960°F (516°C) and then subjected to an increased pressure of 10 ksi (6.9×10^7 N m^{-2}) for a half hour. This process results in a fully consolidated composite shaft having a steel outer shell and an aluminium inner sleeve reinforced by axially aligned boron filaments to enhance bending stiffness.

The invention will be further described by way of example with reference to the accompanying drawings in which:

Figure 1 is a perspective view of one end of a fabricated shaft according to the invention;

Figure 2 is a sectional view taken along a longitudinal plane through the axis of the shaft of Figure 1.

A complete shaft 1 constructed according to this invention is illustrated in Figures 1 and 2 and consists of a hardened steel tubular outer shaft 2 including hardened splines 6 to which is bonded on its inner surface a high specific modulus layer 3. The layer 3, as best seen in Figure 2, consists of a fully consolidated aluminium matrix in which multiple boron filaments 4 are embedded in general alignment with axis 5.

The layer 3 is formed from 7 mil (0.18 mm) thick aluminium matrix tape with 5.6 mil (0.14 mm) diameter boron filaments sandwiched inside. A titanium tape could also be used, but in that instance silicon carbide or boron carbide coated boron filaments should be used to prevent interaction between the titanium and boron.

To fabricate the completed shaft the layer 3 is rolled onto a mild steel mandrel and is inserted into the tubular steel shaft 2. This assembly is then placed into an autoclave in which the pressure is then raised to an intermediate pressure of 4 to 5 ksi ($2.8 - 3.5 \times 10^7$ N m^{-2}). By raising the temperature at this point to 960°F (516°C) the ductility of the layer 3 and its mandrel are increased to facilitate the initial stages of bonding. As a final step, the pressure is then elevated to 10 ksi ($6.9. \times 10^7$ N m^{-2}) and held for approximately a half hour to allow complete consolidation. The mandrel is then removed through a chemical milling process.

The turbine shaft 2 can be constructed of either steel or titanium to insure torsional integrity of the composite shaft. A typical shaft 1 could have a steel or titanium outer sheath having an outside diameter of 1 inch (25.4mm) and an interior diameter of .625 inch (15.9 mm) with a .070 inch (1.78 mm) thick boron/aluminium layer 3 bonded on the interior surface.

In this manner a composite shaft is constructed having a high specific modulus which provides a greater critical speed. Since the outer surface is constructed of steel, it may be machined or welded as required.

To avoid the use of an autoclave, the assembly of the shaft and mandrel may be sealed and evacuated. The assembly could then be pressurized through an internal axial passage within the mandrel. By pressurizing under high temperature consolidation and diffusion, bonding of the tape and the tape to the shaft can be assured.

CLAIMS

1. A composite shaft having a high specific modulus comprising:

an outer tubular sheath constructed of machinable high torsion resistant material and having an interior axially extending passage; and

an interior shell constructed of a metal matrix containing axially aligned filaments of a high modulus material, said shell being completely consolidated and bonded on the inner surface of the tubular sheath.

2. A composite shaft as claimed in claim 1, wherein the tubular sheath is constructed of steel.

3. A composite shaft as claimed in claim 1, wherein the tubular sheath is constructed of titanium.

4. A composite shaft as claimed in claim 1, 2 or 3 wherein the metal matrix is aluminium.

5. A composite shaft as claimed in claim 1, 2 or 3 wherein the metal matrix is titanium.

6. A composite shaft as claimed in any one of claims 1 to 5 wherein the high modulus material is boron.

7. A composite shaft as claimed in any one of the preceding claims, wherein the metal matrix is formed from a metal matrix tape having the filaments sandwiched therein.

8. A composite shaft having a high specific modulus substantially as hereinbefore described with reference to the accompanying drawings.

9. A method of fabricating a composite shaft having a high specific modules comprising the steps of:

constructing an outer tubular sheath of machineable high torsion resistant material and having an interior axially extending passage;

constructing a metal matrix tape having longitudinally extending high modulus material filaments imbedded therein;

rolling the matrix tape on a mandrel with the high modulus filaments orientated in an axial direction;

inserting the tape and mandrel into the axially extending passage to be in close contact with the inner surface of the tubular sheath; and

subjecting the said assembly to sufficient temperature and pressure to achieve consolidation and diffusion bonding of the filament reinforced metal tape into the outer tubular sheath.

10. A method as claimed in claim 9, wherein consolidation is achieved by:

placing the said assembly in an autoclave;

raising the pressure in the autoclave to an intermediate level;

increasing the temperature in said autoclave to a temperature which increases the ductility of the mandrel and film and promotes bonding; and

further raising the pressure in the autoclave to promote bonding and consolidation and holding the pressure until the processes are complete.

11. A method as claimed in claim 9 or 10, wherein the outer tubular sheath is of steel.

12. A method as claimed in claim 9 or 10, wherein the outer tubular sheath is of titanium.

13. A method as claimed in any one of claims 9 to 12, wherein the metal matrix tape is formed by sandwiching longitudinally aligned filaments between two thin films of metal.

14. A method as claimed in claims 9 to 13, wherein the metal matrix is constructed of aluminium.

15. A method as claimed in any one of claims 10 to 14, wherein the high modulus filaments are constructed of boron.

16. A method as claimed in claim 10 wherein the intermediate pressure level is 4 to 5 ksi ($2.8 - 3.5 \times 10^7$ N m^{-2}) and the final pressure is 10 ksi (6.9×10^7 N m^{-2}).

17. A method of fabricating a composite shaft, substantially as hereinbefore described with reference to the accompanying drawings.

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